

**STATE OF CALIFORNIA
AIR RESOURCES BOARD**

**MEETING OF THE
RESEARCH SCREENING
COMMITTEE**

**October 28, 2011
9:00 a.m.**

**Air Resources Board
Research Division
Cal/EPA Building
1001 I Street
Sacramento, CA 95814
(916) 445-0753**

**State of California
AIR RESOURCES BOARD**

**Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Conference Room 550, 5th floor
Sacramento, California 95814
(916) 445-0753**

**October 28, 2011
9:00 a.m.**

AGENDA

- | | |
|---|--------|
| I. Approval of Minutes of Previous Meeting
June 9, 2011 | iii-vi |
| II. Discussion of Final Draft Reports | |
| 1) "Spatiotemporal Analysis of Air Pollution and Mortality in California Based on the American Cancer Society Cohort," University of California, Berkeley, \$749,974, Contract No. 06-332 | 1 |
| 2) "Assessing Near-Field Exposures from Distributed Residential Wood Smoke Combustion Sources," California Polytechnic State University, San Luis Obispo, \$320,286, Contract No. 07-308 | 5 |
| 3) "Physicochemical and Toxicological Assessment of the Semi-Volatile and Non-Volatile Fractions of PM from Heavy-Duty Vehicles Operating with and without Emissions Control Technologies," University of Southern California, \$677,950, Contract No. 05-308 | 11 |
| 4) "Reducing Emissions of Volatile Organic Compounds (VOCs) from Agricultural Soil Fumigation: Comparing Emission Estimates Using Simplified Methodology," United States Department of Agriculture, \$150,000, Contract No. 07-332 | 17 |
| 5) "Using Pb and Sr Isotopes to Assess Asian Aerosol Impacts in Urban and Interior California," University of California, Berkeley, \$80,806, Contract No. 07-318 | 23 |

6) “Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers and Ozone Depleting Substances,” Institute for Research and Technical Assistance, \$199,840, Contract No. 07-313	27
7) “Lifecycle Analysis of High-Global Warming Potential Greenhouse Gas Destruction,” ICF International, \$297,766, Contract No. 07-330	33
III. Discussion of New Research Projects	
1) “Black Carbon and the Regional Climate of California,” University of California, San Diego, \$24,080, Contract No. 08-323	41
2) “Investigate the Durability of Diesel Engine Emissions Controls,” \$300,000, RFP No. 11-304	
3) “Emissions of Potent Greenhouse Gases from Appliance and Building Waste in Landfills,” \$250,000, RFP No. 11-303	
IV. Staff update on 2011 Annual Research Plan	

**State of California
AIR RESOURCES BOARD**

**Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Conference Room 510
Sacramento, California 95814
(916) 445-0753**

**June 9, 2011
9:00 a.m.**

MINUTES

RSC Members in Attendance

Harold Cota – via teleconference
Steven Japar – via teleconference
Matt Kahn – via teleconference
Chung Liu – via teleconference
Irva Hertz-Picciotto – via teleconference
Suzanne Paulson – via teleconference
Forman Williams

Public in Attendance

Skip Brown (Delta Construction Company)
Hank de Carbonel (California Concrete
Pumpers Alliance)
James Enstrom (UCLA) – via teleconference
Matt Malkin (UCLA) – via teleconference

Staff

Alvaro Alvarado
Michael Benjamin
Chris Bowman
Trish Chancey
John Collins
Bart Croes
Cynthia Garcia
James Goldstene
Jorn Herner
Shaohua Hu
Bob Jenne
Ash Lashgari
Eileen McCauley
Chandan Misra
Gennet Paauwe
Emma Plasencia
Linda Smith
Steve Storelli
Monica Vejar
Barbara Weller
Poh-Sin Yap

The Research Screening Committee (RSC or Committee) convened the meeting at 9:10 a.m. The minutes of the April 28, 2011 meeting were approved.

Draft Final Reports

1. "Collaborative Lubricating Oil Study on Emissions," South Coast Air Quality Management District, \$100,00, Contract No. 06-324

The Committee had the following comments:

- The report had too many scenarios and didn't provide a concise summary. A few members pointed out that the Executive Summary partially fulfilled that deficiency by providing a brief synopsis of conclusions.
- The results were based on a small sample size (32 vehicle experiment) and were inconclusive. The current work should be used as a guide to future studies.
- The difference in particulate matter (PM) emissions from fresh vs. aged oil was interesting. Additional work in the future to explore this area was suggested.
- It was unclear why PM emissions from 10 percent ethanol (E10) in normal-emitting vehicles were higher than gasoline (E0). Staff responded that the results are consistent with other studies, but the actual cause is still unknown. Additional work is needed to provide mechanistic details why E10 results in higher PM emissions.
- It was unfortunate that the oil consumption rate was not measured for all the vehicles tested.

The Committee asked staff not to send a secured pdf document in the future. The Committee also asked that the watermark be removed in the future from the documents. Staff clarified that the report was received from the sponsor and forwarded to the Committee as is. Staff will try to get unsecured copy from sponsors in the future.

Motion: Move to accept.

The Committee accepted the report.

2. "Characterization of Toxicity as a Function of Volatility of Ultrafine PM Emissions from Compressed Natural Gas Vehicles," West Virginia University, \$349,996, Contract No. 07-340

The Committee noted that this is a clearly written report. They asked how the toxicity assay data associated with this test program will be presented, and who will be responsible for reporting and analyzing the data. Staff explained that West Virginia University (WVU) has met the scope of work under their contract, and that Air Resources Board (ARB) has contracted separately with University of Wisconsin - Madison, UCLA, and UC Davis for toxicity related assays including trace metals, macrophage Reactive Oxygen Species (ROS), Dithiothreitol (DTT), and mutagenicity analysis. ARB will receive and analyze the currently missing data and prepare an addendum for the report.

The Committee asked that the data in the WVU report be put in context with other heavy-duty vehicle test data. Staff agreed to have WVU include a brief comparison of criteria pollutant data from this test program with data from other test programs. Staff also explained that ARB will lead a comparison of the results from this project with the results from other ARB-funded vehicle emission projects. The findings will be presented in a ARB report and summarized in one or more peer-reviewed journal articles.

The Committee suggested presenting the data in a per mile basis rather than per brake horsepower-hour basis. Staff explained that reporting emissions in units of per brake horsepower-hour provides a comparison with the current heavy duty diesel vehicle emission standards. The data in the report is also presented on a per mile basis.

The Committee suggested removing 'toxicity' from the report title to clarify what has been presented in the report. Staff agreed to have WVU change the report title accordingly.

The Committee also suggested revising the last sentence in the executive summary and conclusions, because it incorrectly gives the impression that university contractors are responsible for delaying the project. Staff agreed to have WVU remove or revise the sentence.

Motion: Motion to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the report.

3. "Flux Measurements of Biogenic Precursors to Ozone and Particulate Matter in the Central Valley," University of California, Berkeley, \$400,003, Contract No. 06-329

The Committee asked how important the spikes in volatile organic compound (VOC) emissions from flowering, harvesting, and other key agricultural events are in the life of an orchard with regards to the 8-hour ozone concentrations and the general ozone season. One Committee member asked if the natural vegetation biogenic emission inventories are truly dominant compared to anthropogenic VOC sources. Staff responded that one needs to be extremely careful in interpreting the differences in base emission factors obtained in this study compared to literature values. The Basal Emission Factors (BEF) is only a small step in the assessment of emission inventories for natural versus agricultural sources. Regarding page 35 of the draft report, staff requested text be added to the section which provides context from previous studies which will help interpret the data. Staff requests that the contractor identify the statistical approach to emission factor development in a more detailed way. On page 41 of the draft report, the Committee pointed out that in combustion literature composition is either described in weight percent or volume percent.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the report.

4. "Spatiotemporal Analysis of Air Pollution and Mortality in California Based on the American Cancer Society Cohort," University of California, Berkeley, \$749,974, Contract No. 06-332

Dr. Dan Costa of the Research Screening Committee (RSC) submitted comments that were supportive of the draft final report which were emailed to the Committee members before the meeting. Written comments were submitted by members of the public: Dr. James Enstrom, UCLA; Skip Brown, Delta Construction Company; and Hank de Carbonel, California Concrete Pumpers Alliance (who provided a letter from Dr. John Dale Dunn). These were emailed and read to the Committee. In addition, Dr. Matt Malkin, UCLA, provided comments by phone. The public comments included questions on the effects of PM on all-cause mortality and how this information is used in the regulatory development process.

After the public comment period, the Committee proceeded to discuss the draft final report. There was an extended discussion on the findings of all-cause mortality and mortality from cardiovascular (CVD) and ischemic heart disease (IHD) and how relevant these health endpoints are to PM_{2.5} impacts. RSC members pointed out that compelling evidence indicates that CVD and IHD are more relevant than all-cause when studying the mortality effects from PM_{2.5}. There were a number of questions from the Committee regarding the methods described in the draft, and a list of concerns on the methods was emailed to staff. There were also questions of how accurately the "conclusions" and "abstract" sections of the report reflect the results reported in the body of the report. The draft report also stated that the mortality results were strongly associated with traffic pollutant exposure, and the Committee thought that this statement needed additional support. Overall, the Committee believed that the report used state-of-the-art techniques and presented an extensive amount of work which can be used to determine the best possible exposure estimates and health estimates in California. However, there were requests for clarifications on the methods and the conclusions.

Motion: Move to table the report, to give the investigator an opportunity to address relevant technical and scientific comments. The revised final draft report and responses will be provided to the Committee members at their next meeting.

The Committee tabled the report.

The meeting adjourned at 11:35 a.m.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 1

DATE: October 28, 2011

CONTRACT NO.: 06-332

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Spatiotemporal Analysis of Air Pollution and Mortality in California Based on the American Cancer Society Cohort

CONTRACTOR: University of California, Berkeley

PRINCIPAL INVESTIGATOR: Michael Jerrett, Ph.D.

BUDGET: \$749,974 (co-funded by South Coast Air Quality Management District)

CONTRACT TYPE: Interagency Agreement

CONTRACT TERM: 36 months

For further information, please contact Dr. Barbara Weller at (916) 324-4816.

I. SUMMARY

The portion of the nationwide American Cancer Society (ACS) cohort living in California (76,000 individuals with over 20,000 deaths for an 18-year follow-up ending in 2000) was used to investigate the statewide health risk associated with exposure to particulate matter (PM) and gaseous air pollution on all-cause and cause-specific deaths. The investigators used twenty individual-level variables to control for confounding of the air pollution-death association from lifestyle, dietary, demographic, occupational, and educational influences, and variables to control for neighborhood-level confounding (e.g., poverty, unemployment). Using multiple statewide models for PM less than or equal to 2.5 μm (PM_{2.5}), the investigators found significantly elevated risks for death due to cardiovascular disease (CVD), with the largest risk for death due to ischemic heart disease (IHD). PM_{2.5} was also associated with all-cause deaths statewide, but only when using the land use regression (LUR) model for exposure and controlling for residence in the largest urban areas. The other pollutants investigated – nitrogen dioxide (NO₂), PM less than or equal to 10 μm (PM₁₀), PM₁₀ sulfates, and ozone – all

showed consistent associations with CVD and IHD that are similar in size to those observed for PM_{2.5}, although the exposure estimates for these pollutants are correlated with each other and with PM_{2.5}.

II. TECHNICAL SUMMARY

Objective

The objectives of the study were: 1) to assess effects from exposure to PM and gaseous air pollution on all-cause and cause-specific mortality in California, based on the ACS cohort; 2) to investigate the impacts on mortality related to proximity to traffic and different particle constituents, and intraurban exposure gradients; and 3) to determine whether critical time windows in exposure exist in the relationship between air pollution and mortality in California.

Background

Epidemiologic studies conducted over several decades have provided evidence suggesting that long-term exposure to elevated levels of PM in ambient air is associated with increased death rates. Two major United States cohort studies, the Harvard Six Cities study and the ACS study came under intense scrutiny in 1997 when the results were used by the U.S. Environmental Protection Agency to support new National Ambient Air Quality Standards for PM_{2.5}. A reanalysis of the ACS cohort, supervised by the Health Effects Institute, added ten years of data, which increased the follow-up time to more than sixteen years and tripled the number of deaths, and used new PM_{2.5} exposure data. The results of this reanalysis indicated a nationwide increased risk of about six percent in premature death for all-causes for each 10 µg/m³ increase in PM_{2.5}. For this contract, the California portion of the ACS cohort was used to estimate the relative health risk for all-cause and cause-specific death in California associated with PM and its constituents and with gaseous air pollution.

Project Summary

The investigators examined the contributions of time, duration, air pollution sources, and level of exposure to death associated with air pollution in California by using the ACS cohort and different statewide exposure models. This study used different statewide exposure models that ranged from basic models such as Inverse Distance Weighting (IDW), to more sophisticated ones such as the integrated LUR model with the Bayesian

Maximum Entropy Kriging model. Also, for the first time, members of the ACS cohort had their home addresses geocoded so that air pollutant exposure levels could be assigned to their residences. This allowed for the more accurate use of exposure and health models. In all, the analysis included 76,000 individuals with over 20,000 deaths for an 18-year follow-up ending in 2000. The investigators used 20 individual-level variables to control for confounding of the air pollution-death association from lifestyle, dietary, demographic, occupational, and educational influences, and variables to control for neighborhood-level confounding (e.g., poverty, unemployment).

With all the statewide exposure models of PM_{2.5}, the investigators found significantly elevated relative risks for CVD, with the largest being observed for death due to IHD. The investigators also found significant associations between PM_{2.5} and all-cause death, but only when using the LUR model for exposure and controlling for residence in the largest urban areas. The investigators determined that their primary finding for PM_{2.5} of elevated risks for CVD and IHD were insensitive to the different exposure or health models used, although there was a trend toward larger risks in more refined exposure models. In addition, the investigators found significantly elevated statewide risk for CVD and IHD associated with exposure to NO₂, PM₁₀, PM₁₀ sulfate, and ozone, although the exposure estimates for these pollutants are correlated with each other and with PM_{2.5}. The NO₂ LUR estimate had significant associations with all-cause, CVD, IHD, and lung cancer deaths. Exposure estimates based on roadway proximity had elevated, but insignificant, risks, suggesting weaker effects than with the NO₂ model, possibly due to increased exposure measurement error. The investigators found a significantly elevated risk for death from all-causes in association with PM_{2.5} exposure in Los Angeles where the monitoring network is capable of detecting intra-urban variations in PM_{2.5}. The risk found in Los Angeles was consistent with that found in an earlier analysis of the Los Angeles ACS cohort by the same principal investigator.

In conclusion, the results from this project found consistent and robust effects of PM_{2.5} and the other highly correlated pollutants on deaths from CVD and IHD. The investigators also found significant associations between PM_{2.5} and all-cause death, although these findings were sensitive to model specification. The statewide risks are comparable to those seen in the most recent national ACS study. These results were

also consistent with past ACS analyses and with findings from other national and international studies.

III. STAFF COMMENTS

This report was presented to the Research Screening Committee (RSC) on June 9, 2011. Following a discussion by the RSC, the Committee asked that the report be modified to contain further explanations and clarifications and be presented to the RSC at a later meeting. The investigators responded by adding the clarifications requested, and the report was reviewed by the staff of the ARB and two outside reviewers. Staff and the two outside reviewers found that the investigators have responded satisfactorily to the comments.

IV. STAFF RECOMMENDATIONS

Staff recommends that the Research Screening Committee approve this draft final report, subject to inclusion of appropriate revisions in response to the staff comments and any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 2

DATE: October 28, 2011

CONTRACT NO.: 07-308

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Assessing Near-Field Exposures from Distributed Residential Wood Smoke Combustion Sources

CONTRACTOR: California Polytechnic State University,
San Luis Obispo

PRINCIPAL INVESTIGATORS: Tracy Thatcher, Ph.D., California Polytechnic State University, San Luis Obispo
Thomas Kirchstetter, Ph.D., Lawrence Berkeley National Laboratory

BUDGET: \$320,286

CONTRACT TYPE: Interagency Agreement

CONTRACT TERM: 48 months

For further information, please contact Peggy Jenkins at (916) 323-1504.

I. SUMMARY

In many California communities, wood is burned for heat and is a significant contributor to winter PM_{2.5}, which often exceeds State and federal standards and exposes individuals to significant health risk. This study examined the effect of near-field wood burning sources on personal exposure. The investigators collected wood smoke samples at pre-determined sites within a 1 km² area as well as meteorological data for 15 nights in Cambria, California, a city with substantial residential wood burning. They also performed modeling studies of wood smoke. Black carbon served as an indicator compound for wood smoke because it is a significant component of soot and wood combustion and was the only major source of black carbon in this area. Large concentration variations were observed for each night both at individual locations and between locations. Sites with the highest overall concentrations (averaged over all nights) had levels 2 to 10 times higher than the lowest concentration sites. Neither multiple linear regression nor dispersion models produced a strong representation of

measured concentrations. Thirteen indoor/outdoor measurement pairs from four different residences showed an average indoor/outdoor concentration ratio of 0.88 ± 0.41 . Based on the measured concentrations, the intake fraction calculated using near-field concentrations was 25 percent higher versus that calculated using the average regional concentration. This study showed that residential wood burning is associated with variable wood smoke concentrations that may lead to higher exposures for some individuals than what would be predicted using data from regional monitors. This finding demonstrates the need to better understand localized wood smoke patterns when developing control plans to protect the public health and welfare by reducing wood smoke levels.

II. TECHNICAL SUMMARY

Objectives

The overall goal of the study was to examine the impact of nearby wood burning sources on personal exposures to wood smoke. The investigators sought to address four primary research questions:

1. What is the concentration variability associated with wood burning within a residential neighborhood?
2. Can near-source contributions be properly estimated based on information on burning patterns, meteorology, and regional monitoring site data?
3. Does indoor exposure to outdoor wood smoke sources correlate with expected values based on simple indoor/outdoor models?
4. How does the near-source contribution affect intake fraction calculations for wood smoke exposures?

Background

Community air pollution concentrations are the result of emissions from many local and distant sources, while various atmospheric processes also affect these concentrations. An individual's exposure to pollutants is determined by the concentrations present in the different microenvironments they visit and the amount of time they spend in those microenvironments, both indoors and outdoors. However, most exposure estimates are derived from regional monitors and then are applied to general populations across

broad areas. Typically, pollution control activities are designed to reduce health risks based on these general exposure estimates. However, it is often difficult to determine realistic, spatially-resolved concentrations and exposure estimates for primary pollutants. Because concentrations of common pollutants, including wood smoke, are highest near their sources, this makes exposures in the near-source environment difficult to estimate.

Estimating the contribution of different source types to individual exposures also is challenging, but a relatively new metric, the intake fraction, has been devised to provide such estimates. The intake fraction describes the mass of a pollutant inhaled divided by the mass of emissions of the pollutant. In order to perform such calculations, it is necessary to know the regional and local emissions of smoke sources and to have data on the local, spatially-resolved smoke concentrations. Ideally, one would obtain data from personal monitoring to perform such calculations, but often this is not feasible.

Wood smoke contains many harmful agents, including carcinogens such as benzene, polycyclic aromatic hydrocarbons, and formaldehyde, as well as particles, other criteria pollutants, and inorganic toxics. The particles from wood smoke contribute a large portion of the PM_{2.5} mass during the winter in some parts of California. Efforts have been made by cities and air districts to reduce wood smoke with measures that range from education to bans on installation of wood burning appliances and no-burn nights. Despite these controls, wood smoke remains an issue of both public health concern and PM standards attainment.

Report Summary

The study took place over two winter seasons and was organized into four tasks to address the study questions listed above. Task 1 was the study site selection. During the initial phase of this task, several California locations were considered, including Fresno, Sacramento, and Concord. However, Cambria was best suited to meet this study's objectives. Residential wood burning is still prevalent in Cambria, and Cambria experiences wintertime inversions, relatively low wind speeds that would lead to higher and more easily measureable concentrations, and limited fog and precipitation that could prevent wood smoke particles from being scavenged from the atmosphere. In

addition, this study site exhibited limited interference from other sources of combustion particles, such as industry and heavy vehicular traffic.

Task 2 included the development of a detailed study plan and method validation. A series of tests were conducted to assess, compare, and refine different analytical methods for quantifying wood smoke concentrations and to validate the selected methods. During the method comparison tests, multiple filter samplers (used for two methods of thermal-optical analysis and one method of light transmission [light attenuation method]) and an aethalometer (which measures time-resolved black carbon concentrations) were co-located at four different sites within the pre-determined 1 km² northern Cambria study area. In addition, samples were collected for a chemical analysis that determined levels of levoglucosan, a specific chemical marker of biomass combustion. The investigators determined that wood smoke was the dominant source for black carbon and that it was a suitable indicator of wood smoke in the Cambria area.

Task 3 of this project was the main field study, which sought to examine the variability of black carbon concentrations within the defined study area. During ideal weather conditions, 15 intensive operation periods (IOP), which were 12-hour sampling periods during which black carbon was collected within the study area, were conducted. During each IOP, black carbon measurements were made using both integrated filter samples and real time aethalometers. The study area was also surveyed using an infrared camera to determine which homes were actively utilizing their chimneys. To determine the indoor concentration due to residential wood burning, pairs of integrated filter samplers were placed indoors and directly outside of four different residences within the study region during some IOPs. In addition, a time dependent mass balance model was used, in conjunction with aethalometer measurements taken over 16 nights at a single residence, to estimate an average air exchange rate for that one home.

Task 4 activities included data analysis and the reporting of results. The concentration variability associated with wood burning within a residential neighborhood (research question number 1) was found to be significant. Over a single 12-hour sampling period, at 1- or 2-minute time resolution, peak black carbon concentrations measured with an aethalometer ranged from 2 to 100 times higher than the average concentration and up

to 2,500 times larger than the minimum recorded concentrations. Substantial variations in black carbon concentrations were detected at each location and between locations. For 12-hour integrated black carbon filter samples, the standard deviation of concentrations for a single sampling period ranged between 20 percent and 150 percent of the average concentration. The absorption Ångström exponents, a metric of how the light absorption of PM varies with wavelength and an indicator of wood smoke, were determined; 95 percent of the time they exhibited high values typically associated with wood smoke rather than motor vehicle exhaust. The near-source contribution could not be accurately estimated using multiple linear regression models or dispersion models based on local meteorological, geographic, and source data. An average indoor/outdoor concentration ratio of 0.88 ± 0.41 indicated that the outdoor concentrations can be somewhat mitigated in the indoor environment by losses to the surfaces and hence, that a simple indoor mass balance model could adequately represent the average protection provided by the indoor environment. The intake ratio (the intake fraction calculated using local concentrations in the study area's sub-regions to the intake fraction calculated using the average concentration for the entire area) ranged between 0.95 and 1.8, with all but two of the values being greater than 1, suggesting that including local effects rather than regional data increased the intake fraction and thus the estimated exposures of local residents. However, a follow up study is required to determine whether it is the home density or the nature of the specific geography of the area that led to this increase.

III. STAFF COMMENTS

Electronic copies of a preliminary draft final report were provided for review and comment to staff of ARB's Research and Planning and Technical Support Divisions. The current draft final report has addressed staff's main comments, and the field work and content of the report meet the contract requirements. Staff has just one significant comment on the final report, and that is that the distribution of intake fractions used to calculate the intake ratios should be included in the report.

This study provides new information on the roles that the number and distribution of wood burning sources, residential wood smoke emissions, atmospheric processes, and meteorology play in determining personal exposure.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to the staff comments and any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 3

DATE: October 28, 2011

CONTRACT NO.: 05-308

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Physicochemical and Toxicological Assessment of the Semi-Volatile and Non-Volatile Fractions of PM from Heavy-Duty Vehicles Operating with and without Emissions Control Technologies

CONTRACTOR: University of Southern California

PRINCIPAL INVESTIGATOR: Constantinos Sioutas, Sc.D.

BUDGET: \$677,950

CONTRACT TYPE: Standard Agreement

CONTRACT TERM: 65 months

For further information, please contact Dr. John F. Collins at (916) 327-8097.

I. SUMMARY

Diesel Particulate Filter (DPF) and Selective Catalytic Reduction (SCR) aftertreatment technologies are being adopted by most manufacturers to comply with the 2007 and 2010 heavy-duty diesel vehicle (HDDV) particulate matter (PM) and nitrous oxides (NO_x) standards. These aftertreatment devices have proven effective in reducing their target pollutants, PM and NO_x, by >95 percent and 80 percent respectively under most conditions. However, their effect on the chemical composition and toxicity of PM is not yet fully understood. PM emissions from vehicles include both semi-volatile and non-volatile compounds. It has been demonstrated that some of the emission control technologies could increase the number emissions of semi-volatile particles. It is therefore important to know whether the semi-volatile material is more or less toxic than the non-volatile particles. This project characterized the physicochemical and toxicology-related properties of the semi-volatile and non-volatile fractions of PM from HDDVs operating with and without aftertreatment control technologies. Four vehicles in seven configurations were tested on ARB's heavy-duty chassis dynamometer over

highway cruise, transient, and idle operation. The aftertreatment devices tested in this study include various DPFs (catalyzed and uncatalyzed) and two prototype SCRs (vanadium and zeolite based). The semi-volatile and non-volatile fractions of PM were separated using thermal treatment methods. A comprehensive dataset was generated, including real-time measurements of particle information (number and size distribution, particle-bound polycyclic aromatic hydrocarbons (PAHs)), and integrated measurements of regulated pollutants (CO, NO_x, THC, PM, and CO₂), unregulated pollutants (PAHs, nitro-PAHs, total and speciated gas-phase NMHC, carbonyls, metals, EC/OC, water-soluble organic carbon, and water-soluble ions), and toxicity related assays (oxidative potential using dithiothreitol (DTT) and macrophage reactive oxygen species (ROS) assays). Unlike the PM from the uncontrolled baseline diesel vehicle, the majority of PM emitted by vehicles with aftertreatment is semi-volatile in nature. The aftertreatment devices reduced the oxidative potential by 60 percent to 98 percent when expressed per vehicle distance traveled; when expressed per unit mass, there were substantial differences among the various devices. Even though the levels of pollutants are substantially reduced, the issue of the toxicological potential of the remaining compounds is still an area of interest.

II. TECHNICAL SUMMARY

Objective

The major objective of this study is to characterize the physicochemical and toxicological properties of the semi-volatile and non-volatile fractions of PM from HDDVs operating with and without emissions control technologies. This project also aims to evaluate the effect of emissions control technologies on PM emissions under different driving conditions (e.g. cruise, transient and idle operation).

Background

Diesel technology plays a vital role in many sectors of the United States economy because of its unique combination of energy efficiency, power, reliability, and durability. However, HDDVs are a major contributor to ambient air PM, and diesel engine exhaust is deemed harmful to human health. ARB and the United States Environmental Protection Agency (U.S. EPA) have gradually tightened heavy duty diesel (HDD) emissions standards since the late 1980's, which in turn have advanced the

development of engine technology and emissions control technologies. It is widely expected that sophisticated aftertreatment technologies, namely DPFs for PM, and selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) for NO_x, will be the most effective methods of meeting the 2007 PM and 2010 NO_x emissions standards. DPFs and SCRs, in addition to filtering soot and converting NO_x, change the character of the diesel engine emissions qualitatively by acting as chemical reactors that create varying degrees of either oxidizing or reducing conditions with associated effects on other exhaust gas species. The extent to which this happens depends on the individual characteristics of the DPF or SCR, with a commensurate scaled effect on the exhaust constituents subject to oxidation-reduction [redox] chemistry. It is known that the emission control technologies can enhance the formation of nano particles via oxidation of sulfur content in the diesel fuel. Measurements of the relative toxicity of these particles compared to the more refractory (non-volatile “accumulation” mode) PM are valuable in terms of assessing the need for additional control strategies.

Project Summary

Four HDDVs in seven configurations were tested at ARB's HDD emission testing laboratory (HDETL) in downtown Los Angeles. The retrofit aftertreatment devices tested in this project include four types of DPFs (catalyzed and un-catalyzed, passive and active); two SCRs (prototype vanadium- and zeolite-based systems); and a DPF equipped hybrid diesel electric drive transit bus. The vehicles were exercised over three driving cycles to simulate various real-world driving conditions: 1) a 50 mph steady state cruise, 2) a transient urban dynamometer driving schedule (UDDS) and 3) idle operation. A suite of samplers was employed to measure the regulated and unregulated pollutants. Two parallel thermal denuders were used to remove the volatile fraction of PM in the diesel exhaust. Detailed physiochemical and toxicological characteristics of PM were measured for each vehicle configuration and driving cycle, including physical properties (e.g. PM mass, number and size distribution), chemical constituents (e.g. EC, OC, organic compounds, trace elements, inorganic ions) and toxicological-related properties [DTT and macrophage (ROS) assays]. The results are summarized below.

Physical Properties

- PM mass from vehicles with aftertreatment devices was reduced by greater than 90 percent, compared with the baseline vehicle.
- Particle number was not always reduced in concert with PM mass reduction due to the additional formation of nucleation mode particles (particle diameter <50µm) under certain driving conditions (e.g. cruise and UDDS cycles).
- Formation of nucleation mode particles depends on the presence of a catalyst, the age of the catalyst, and the exhaust temperature.
- The nucleation mode particles largely evaporated between 150 to 230°C.

Chemical Properties

- Major chemical constituents (e.g. TC, OC, EC, and organic compounds) were significantly reduced by the aftertreatment devices.
- Sulfate dominated the PM composition in vehicle configurations with substantial nucleation mode particle formation,
- TC was dominant for the configurations with no or insignificant nucleation.
- DPF + SCR effectively reduced PAHs, hopanes and steranes, n-alkanes and acids by more than 99 percent, and often to levels below detection limits for both cruise and UDDS cycles. SCR also enhanced removal efficiencies for other organic compounds.

Toxicity (Oxidative Potential)

- Despite a notable increase in the intrinsic activity of both DTT and ROS expressed on a per PM mass basis for vehicles with retrofits compared to baseline, the overall activity of both DTT and ROS expressed on a per km or per hour basis was reduced for vehicles with retrofits compared to the baseline.
- Significant reduction in DTT activity (by 50-100 percent) was observed for thermally-denuded PM samples from vehicles with aftertreatment technologies, indicating a significant fraction of DTT activity was due to semi-volatile particles.
- Chelation of PM sample extracts removed a substantial (≥70 percent) fraction of the ROS activity, indicating that much of the ROS activity is due to metals

- DTT activity is strongly associated ($R=0.94$) with water soluble organic carbon (WSOC), while the ROS activity was mostly driven by the Fe content of the PM samples.

III. STAFF COMMENTS

Staff reviewed this report and provided comments to the investigators. The investigators were responsive to comments, and staff is satisfied with the quality of work performed and the quality of the draft final report.

This project provided a comprehensive dataset for the physical, chemical and toxicological properties of PM emitted from HDDVs retrofitted with various diesel particle filters and prototype SCRs. The results demonstrate the effectiveness and effect of the latest emission control devices on PM emissions. The results provide a preview of the PM emissions of OEM 2007- and 2010-compliant HDDVs. Importantly, this project revealed the relative toxicity of the semi-volatile fraction of PM, which is an original contribution of major significance to the assessment of the health impacts of technologies used to meet the latest HDD emission standards. The results from this project substantially advance our understanding of the latest emission control technologies.

Additional information on the regulated pollutants (including CO, CO₂, THC, and NO_x), formation of nucleation mode particles, and metal compounds can be found in companion journal articles published by staff.

STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to the staff comments and any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 4

DATE: October 28, 2011

CONTRACT NO.: 07-332

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Reducing Emissions of Volatile Organic Compounds (VOCs) from Agricultural Soil Fumigation: Comparing Emission Estimates Using Simplified Methodology

CONTRACTOR: United States Department of Agriculture - Agricultural Research Service

PRINCIPAL INVESTIGATOR: Scott R. Yates, Ph.D.

BUDGET: \$150,000

CONTRACT TYPE: Standard Agreement

CONTRACT TERM: 36 months

For further information, you may contact Dr. Dongmin Luo at (916) 324-8496.

I. SUMMARY

Volatile organic compounds (VOCs) are active ingredients of soil fumigants used in agricultural fields to control pests. As ozone precursors, fumigant VOCs contribute to exceedances of ozone air quality standards in the San Joaquin Valley of California. However, large uncertainties exist in both the estimates of their baseline VOC emissions and reductions achievable from emissions control strategies. This project studied emissions of three fumigant VOCs: 1,3-dichloropropene (1,3-D), chloropicrin (CP), and methyl iodide (MeI), in both laboratory experiments and modeling simulations under five soil fumigation practices:

1. intermittent sprinkler irrigation following fumigation;
2. soil organic amendment;
3. deep injection;
4. application of fertilizer ammonium thiosulfate (ATS) and

5. soil surface seal with various plastic films. All of the tested strategies reduced 1,3-D and CP emissions.

Soil surface seal with virtually impermeable film (VIF) was the most effective method, which reduced VOC emissions by over 95 percent, followed by soil organic amendment (80-85 percent), intermittent sprinkler irrigation (50 percent), and ATS with irrigation (43-88 percent), ATS with low water-volume spray (26-42 percent), and deep injection (23-36 percent). Covering the soil surface with a VIF was also the most effective in reducing MeI emissions. In addition, both laboratory and modeling approaches generated total emission estimates for 1,3-D comparable to the field conditions but less satisfactory for CP. All flux models predicted the emissions of MeI well. Although the accuracy of these approaches varied, their variability was within the experimental uncertainty expected in field studies.

II. TECHNICAL SUMMARY

Objectives

The objectives of this project were:

1. to evaluate the emission rates and mitigation potential of three soil fumigant VOCs using simplified experimental and modeling approaches, and
2. to determine if these methodologies can adequately represent full-scale field studies to derive emission estimates for fumigant VOCs.

Background

Fumigant VOCs are of concern in the San Joaquin Valley of California, which has vast agricultural acreage. VOCs react in the atmosphere to form ground-level ozone which causes health problems. California's State Implementation Plan requires the State to track and control fumigant VOC emissions in ozone non-attainment areas. Accounting for VOC emissions from soil fumigation, however, presents a challenge because volatilization of VOCs from soil fumigants varies appreciably due to management practices, soil characteristics, and weather conditions.

Prior to 2007, the Department of Pesticide Regulation (DPR) estimated fumigant VOC emissions based on assuming 100 percent VOC volatilization. This method ignored losses of VOCs in soil due to processes such as irreversible sorption and degradation once a fumigant is applied to the field. Recently, DPR modified its estimation procedure,

considering not only the fumigant VOC contents but also the fumigation methods. However, there are large uncertainties in both the estimates of baseline VOC emissions and reductions achievable from emissions control strategies.

This project evaluated emissions of two commonly used fumigants: 1,3-D, commonly known as Telone® II, or 1,3-D with CP, commonly known as Telone® C-35, and one newly registered fumigant Mel under several soil fumigation practices intended as emission control strategies, and explored methodologies that can be used to obtain improved emission estimates for fumigant VOCs.

Project Summary

This project was conducted to determine whether simplified experimental systems and modeling tools can be used to estimate emissions of fumigant VOCs under field conditions. Laboratory experiments were designed to reproduce conditions of the 2005 and 2007 field studies that tested the following soil fumigation practices:

1. intermittent sprinkler irrigation following fumigation;
2. soil organic amendment;
3. deep injection; and
4. application of ATS fertilizer (with or without irrigation).

A 5th strategy, soil surface seal with various plastic films, which was not used in the 2005 and 2007 field studies, was also tested. Modeling studies with one or more flux models of different complexity (Hydrus 1D, Hydrus 2D, Solute 1D, and an algebraic analytical solution) were also performed to simulate VOC emissions for each experiment.

Three laboratory systems were used: soil columns, soil chambers, and soil beds. Laboratory soil columns (12 cm diameter x 150 cm long) were packed with soil at the same incremental density and moisture content as observed in the field. The temperature of the top 30 cm of soil was controlled to create a diurnal pattern and the temperature at the bottom was kept constant by insulation. Liquid fumigant containing 1,3-D alone (Telone® II) or 1,3-D with CP (Telone® C-35), or Mel alone, was injected into the soil with syringe to simulate shank application in the field, and emission fluxes at the soil surface were then monitored by withdrawing the headspace air of the column

for GC analysis. The soil chambers (120 cm high x 80 cm wide x 10 cm thickness) were prepared containing both a soil bed (50 cm wide) and a furrow (30 cm wide), with their headspace compartments separated at the top so that air samples could be taken independently. The temperature of the chamber was controlled under the same regimes as for the columns, as described above. Telone® C-35 (1,3-D and CP) was injected into the soil bed through a sealable port, followed immediately by 2-hour drip irrigation. Emissions of the VOCs were then monitored by measuring headspace VOCs as for soil columns.

The soil bed (4.5 m long x 1 m wide x 17 cm high) experiments were conducted outdoors. Telone® C-35 solution was applied to the soil through irrigation drip lines from a barrel reservoir. Each soil bed was equipped with a dynamic flux chamber connected to a vacuum pump which pulled air at a flow rate of typical wind speed. A subsample of the air flow from the flux chamber, monitored by a data logger, was directed to a sorbent tube to capture the VOCs for GC analysis. All soil column and chamber experiments were performed in duplicate and soil bed experiments were performed using a triplicate randomized block design. The monitoring was conducted for 12 to 16 days after fumigant application to allow the VOC fluxes to drop to near background levels.

Emissions of 1,3-D were studied in 22 of the 26 experiments. The average total emission loss of 1,3-D under the conventional fumigation application was 37 percent, compared to 31 percent for the 2005 and 2007 field studies. Total emissions were reduced by approximately 80-85 percent by soil organic matter amendment, 50 percent by intermittent irrigation, 43 percent by ATS with single irrigation, 36 percent by deep injection, and 26 percent by ATS spray with no irrigation. Emissions were almost completely eliminated by surface seal with virtually impermeable films (VIF), but were not affected by a standard permeability film (HDPE: high density polyethylene). The flux models predicted the emission results well, except for a few incidents involving ATS and shallow injections. Additional model development is needed to improve methods for simulating the ATS-fumigant interactions.

Emissions of CP were studied in 18 of the 26 experiments. Total emission loss was 18.4 percent, significantly higher than those of the field studies (< 2 percent in all

cases). The emissions were reduced by over 95 percent by use of plastic films (HDPE and VIF), 88 percent by ATS with single irrigation, 42 percent by ATS spray with low water-volume spray, and 23 percent by deep injection. However, the flux models either under- or over-predicted the measured emissions for this fumigant, except for the VIF treatment where the total emission losses were < 0.01 percent.

Emissions of Mel were studied in four experiments. Total emission loss was 83 percent for control (bare soil), 63 percent by soil organic amendment, and was essentially eliminated by VIF, but was unaffected by repeated irrigation. The significantly higher emission rates of Mel than 1,3-D and CP were attributed to its longer persistence in soil, which is about twice that of 1,3-D and ten times that of CP. All flux models predicted the emissions of Mel well, with the predicted results 11 to 46 percent less than the observed values. Since Mel was not tested in the 2005 and 2007 field studies, no conclusions were drawn regarding whether the emission estimates provided by these methods can be used to represent those from field conditions.

III. STAFF COMMENTS

This project, funded jointly by ARB and DPR, was a follow-up to a previously ARB-funded project (2005-2007) to evaluate mitigation strategies for fumigant VOCs used in agricultural fields. The Principal Investigator fulfilled all tasks set forth in the proposal. The current project provided comprehensive information on the effectiveness of potential mitigation measures for fumigant VOCs.

A previous version of the report was reviewed by staff from the Research Division and the Planning and Technical Support Division, and the agriculture community via the San Joaquin Valley Air Pollution Control District's Agriculture Technical Committee. The comments provided by staff have been satisfactorily addressed in the current version.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee accept this draft final report subject to inclusion of appropriate additions and revisions in response to any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 5

DATE: October 28, 2011

CONTRACT NO.: 07-318

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Using Pb and Sr Isotopes to Assess Asian Aerosol Impacts in Urban and Interior California

CONTRACTOR: University of California, Berkeley

PRINCIPAL INVESTIGATORS: Don DePaolo, Director, Center for Isotope Geochemistry, University of California, Berkeley, and John Christensen, Earth Science Division, Lawrence Berkeley National Laboratory

CONTRACT TYPE: Interagency Agreement

BUDGET: \$80,806

CONTRACT TERM: 52 Months

For further information, please contact Dr. Eileen McCauley at (916) 323-1534.

I. SUMMARY

The global-scale transport of airborne pollutants increases the local “background” pollutant burden in California. Asian dust and fuel-related combustion products are known to be regularly transported to California. Growth of Asian emissions will increase this background burden and may complicate attainment of air quality standards. Asian aerosols dominate the mean composition of the lower free troposphere over California, but chemical and elemental analyses cannot unequivocally measure the mass fraction of Asian aerosols in urban or agricultural areas where local sources mask their chemical signatures. Ratios of stable isotopes of Pb are diagnostic “fingerprints” for source rock bodies for metal ores, soils, and native impurities in fossil fuels. Similarly, stable isotope ratios of Sr and Nd are known to be diagnostic of their parent terranes, and these have been used to identify Asian dust in polar ice. This project used source-linked Pb and Sr isotopic fingerprints measured in aerosol samples from Asia and California to assess Asian contributions of both fugitive dust and combustion products in rural and urban

aerosol samples from California. For samples analyzed in this project, 72 percent of Pb at Mt. Tamalpais was of Asian origin, as expected for a clean elevated site. By using the fraction of Asian Pb to estimate total Asian PM_{2.5} at Mt. Tamalpais, and applying that to the Asian Pb observed in Berkeley, it was estimated that, for the week of July 21, 2008, approximately 45 percent of the PM_{2.5} at Chabot Observatory in the Oakland Hills was sourced in Asia.

II. TECHNICAL SUMMARY

Objective

The objective of this project was to exploit the difference between source-linked lead (Pb) and Strontium (Sr) isotopic fingerprints for Asia and California. By comparing fingerprints from pure Asian aerosol collected in Asia and above the Pacific coast to samples collected elsewhere in California, including urban areas, it is possible to assess Asian contributions of both fugitive dust and combustion products to the total particle mass in a sample. This project included both a proof of principle and a demonstration sampling effort focusing on the San Francisco Bay Area (Berkeley).

Background

Asian dust and combustion products are known to be regularly transported to California. High altitude monitoring data show that Asian aerosols dominate the mean composition of the lower free troposphere over California, while sparse data from a few coastal sites show much smaller sea-level impacts. The burden of Asian pollutants at low altitude inland sites is expected to be greater than at the coast, although there are no published data on this impact. Data from urban and agricultural regions are needed to assess current and future Asian impacts on California air quality, especially in non-attainment areas. Although Asian dust has a distinct chemical composition, the general similarity of combustion-products from both sides of the Pacific Ocean render chemical and elemental analyses unreliable to isolate the mass fraction of Asian aerosols in urban or agricultural areas of the State.

Ratios of stable isotopes of Pb are well-known to be diagnostic “fingerprints” for source ore bodies, and are thus markers for emissions from dust, metal processing and combustion emissions associated with Pb from those ores. This has been used in the past to track the sources of Pb pollution on local and regional scales. Similarly, stable isotope ratios of Sr and Nd are known to be diagnostic of their parent rocks, and these

have been used to identify Asian dust in polar ice. This project exploited source-linked Pb and Sr isotopic fingerprints measured in aerosol samples from Asia and California to assess Asian contributions of both fugitive dust and combustion aerosol in California.

Project Summary

The project developed sampling and analysis techniques suitable for aerosol isotopic analysis for naturally occurring isotopes of lead (Pb) and strontium (Sr), then analyzed samples collected in California and Asia. The investigators used existing samples from Hefei, China and high-altitude Californian sites to characterize the Asian Pb signature, validated by comparison with literature values. Samples collected under this contract were used to measure the Asian Pb in PM_{2.5} at Mt. Tamalpais and in Berkeley, and, using archived samples, measure Asian Pb fractions at other sites in the State, as well. The project demonstrated that there are strong and consistent isotopic contrasts between aerosols sourced in Asia (China) and local aerosols in California that make Pb source discrimination and apportionment possible. Relating Pb fractions to total aerosol in predominantly Asian samples from Mt. Tamalpais permitted estimation of the total Asian fraction of aerosols in paired samples collected in Berkeley, where the chemical (but not isotopic) signature of the Asian material is masked by local pollutants. For example, during the week of July 21, 2008, Asian material constituted about 45 percent of total PM_{2.5} sampled in Berkeley. The project also demonstrated that Pb and Sr isotopic and elemental compositions could be determined from routine monitoring, using historical samples selected from the ARB sample archive and from the IMPROVE network. The project succeeded in its objective to demonstrate that it is possible to use spatially and temporally coordinated samples from low-altitude urban and nearby “clean” rural sites to routinely evaluate the fractional contributions of Asian aerosols to the PM_{2.5} composition in an urban area.

III. STAFF COMMENTS

A preliminary draft of the report was submitted to ARB for early review, and the draft final report submitted to the RSC incorporates recommended changes. The report presents results that cover the goals outlined in the Interagency Agreement, along with additional results obtained through additional funding provided by Center for Isotope Geochemistry and Lawrence Berkeley National Lab. In addition, it is organized to

conform to the ARB standard format, covers the significant features of the work done, and discusses the significance of the findings.

IV. STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to staff review and any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO.: 6
DATE: October 28, 2011
CONTRACT NO.: 07-313
[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers, and Ozone Depleting Substances

CONTRACTOR: Institute for Research and Technical Assistance (IRTA)

PRINCIPAL INVESTIGATOR: Katy Wolf, Ph.D.

BUDGET: \$199,840

CONTRACT TYPE: Standard Agreement

CONTRACT TERM: 44 months

For further information, please contact Pamela Gupta at (916) 327-0604.

I. SUMMARY

The objective of this project was to develop a bottom up inventory of California greenhouse gas (GHG) emissions and banks from certain applications and to analyze methods of reducing or eliminating the emissions. The applications included solvent applications, fixed total flooding and portable fire extinguishers, dry cleaning, use in implantable medical devices, and cleaning of energized electrical equipment. The approach relied on information from air districts, equipment installers, and suppliers to generate estimates of emissions and banks. The results demonstrated that emissions will decline from 2010 to 2020 because of trends already underway. Cumulative emissions from solvent and fire protection applications are estimated at 0.185 and 0.363 million metric tons of carbon dioxide equivalent respectively over the ten year period. Cumulative emissions from other applications that were analyzed are estimated at 0.017 million metric tons of carbon dioxide equivalent. The project also involved investigating non-GHG alternatives and alternatives that are reasonably cost effective.

These alternatives were identified for most applications. ARB policies could reduce emissions further, particularly in solvent applications.

II. TECHNICAL SUMMARY

Objective

The objective of the project was to develop an inventory of California GHG emissions and banks for certain applications and to analyze methods of reducing or eliminating the emissions. This objective consisted of four parts: to characterize use of the GHG in its specific applications of interest; secondly, to evaluate trends in use of the GHG in its applications of interest; thirdly, to estimate current and future baseline emissions of the GHG; and fourthly, to analyze methods of reducing or eliminating emissions of the GHG.

Background

GHGs including perfluorocarbons (PFCs), perfluoropolyethers (PFPEs), hydrofluorocarbons (HFCs), hydrofluoroethers (HFEs), and ozone depleting substances (ODSs) have been used in solvent applications for many years since they have low flammability and are gentle enough to clean precision parts and they evaporate quickly leaving a dry part; they also are non-VOC compounds. There are three principal solvent applications that rely on the use of these GHGs including film cleaning, vapor degreasing, and disk lubrication. In film cleaning, the compounds are used by the movie industry to clean original negative and archived film during processing to remove fingerprints and particle contaminants. In vapor degreasing, the solvents and blends of solvents are used to remove various contaminants like oils, flux, and particles from metal and plastic parts in general and precision cleaning. The compounds used in vapor degreasing capitalize on the physical properties of the halogenated solvents to effectively clean parts and that they can be heated to their boiling points without the risk of fire. In disk lubrication, the solvent is used as a carrier for a lubricant that is deposited on hard disk surfaces. The solvent is used to dilute the lubricant allowing a very thin deposit of lubricant to be left on the surface after evaporating the solvent.

There are two fire protection applications that rely on the use of these compounds: fixed total flooding systems and portable fire extinguishers. In total flooding systems these

compounds are used to flood the room if a fire occurs mainly to protect expensive electronic equipment and data that could be destroyed. Portable fire extinguishers are used in a variety of places including marine and aerospace facilities for local fire protection. Prior to the United States ban on the production and importation of Halon 1301 and 1211 in 1994 under the Clean Air Act in compliance with the Montreal Protocol these were the most common agents for the total flooding and portable fire extinguishers respectively.

Three other applications that rely on stockpiled GHGs were identified. These are dry cleaning of delicate garments and costumes in the movie industry, use of inert material in implantable devices by medical device manufacturers, and cleaning of energized electrical equipment.

Project Summary

This project involved developing bottom up estimates of emissions from solvent applications. Using information from permits from local air district and discussions with industry representatives, emissions from the three applications were developed for a baseline year, 2010, and were projected under a business as usual (BAU) scenario for 2020. Two alternative emission projections were also developed to take into account other potential conditions and trends during the period. The analysis also involved investigating potential non-GHG alternatives and alternative processing methods for reducing emissions and estimating the costs of using them. For all three solvent applications the Institute for Research and Technical Assistance (IRTA) estimated cumulative emissions over the ten year period.

The project results indicate that emissions of solvents from film cleaning will decline over the period because of the trend to digital technology. Emissions from vapor degreasing will also decline because of a production ban for the principal ODS compounds used. Alternative non-GHG solvents will be used as will airtight alternative equipment with either GHG or non-GHG solvents. The airtight equipment will reduce emissions by an estimated 90 percent. Most production of hard disk computer equipment has been moved out of the country leaving primarily R&D operations in California. IRTA was not able to get specific GHG use information from the hard disk manufacturers and so used the air district permit information and assumed that there

would be little if any change in use between 2010 and 2020. Total solvent emissions are expected to decline from 0.028 to 0.011 million metric tons CO₂ equivalent per year. In all three applications non-GHG and low Global Warming Potential (GWP) alternatives are available and cost effective.

Bottom up estimates of the bank of agents in fire protection equipment in the state in 2010 were also developed. IRTA worked with system installers to estimate the number of systems and the types of GHGs used. It also involved developing projections of the 2020 bank under BAU conditions. Based on the size of the bank and losses from the equipment, emissions were estimated for the period from 2010 and 2020. Two alternative scenarios for total flooding systems and portable extinguishers were developed for the size of the bank emissions for 2020. The analysis also included analyzing and investigating the GHG alternatives and comparing the cost of using them. For both applications, IRTA estimated the cumulative emissions over the ten year period.

Alternatives to Halon 1301 in total flooding systems include not-in-kind materials like powdered aerosols, water sprinklers, water mist systems, and foams. CO₂ is used in some systems in unoccupied spaces. Inert gases such as argon and nitrogen are used in some new systems. A range of alternative non-ODS GHG compounds such as PFCs, HFC-227e, and HFC-125 are also used. A new perfluoroketone type agent with a very low GWP is now being used in some new systems.

Portable handheld and wheeled fire extinguishers in the past relied on Halon 1211. When the production ban on Halon 1211 became effective, most applications where clean agents were not required were converted to not-in-kind alternatives like dry chemicals, water, and foam. Halotron I was developed to replace Halon 1211 in portable fire extinguishers where a clean agent is needed. Another alternative that has been used is HFC-236fa.

Emissions from fire protection applications are expected to decline from 0.059 to 0.018 million metric tons CO₂ equivalent.

Dry cleaning solvents based on CFC-113 have been used to clean delicate garments, principally costumes in the motion picture industry. Since production of CFC-113 has

been banned, current uses are based on stockpiled material. The stockpile of CFC-113 is expected to be depleted by 2020. Based on information from the motion picture industry, IRTA estimated that there is a maximum stockpile of 5 drums. Maximum emissions of 0.008 million metric tons of CO₂ equivalent are expected. There are several alternatives available; each has tradeoffs between cleaning effectiveness, cost, and other environmental concerns such as VOC controls and toxicity.

Medical device manufacturers have also used CFC-113 as a carrier medium in implantable medical devices. IRTA found that medical device manufacturers in California may have up to 5 drums of CFC-113. This material will likely last until the medical devices become obsolete. Alternative materials with the required low toxicity and inertness exist.

Utilities must routinely clean energized electrical equipment at generating stations. Many suppliers and utilities still have stockpiled HCFC-141b for these purposes. Alternatives exist for when these stockpiles are expended.

The emissions estimates that were developed during the project were compared with estimates from U.S. EPA and two trade associations. For solvent applications, IRTA's emission estimates were much lower than those from U.S. EPA's Vintaging Model, although the Vintaging Model itself has produced much lower results in 2011 as compared to 2001. The Vintaging Model is a national model and must be factored for California specific results. In addition, the Vintaging Model used different system lifetime and emission rate assumptions than IRTA assumed from the California information they gathered. For fire protection applications, IRTA's HFC emission estimates compared well with trade association estimates and both of these estimates were lower than those of the EPA's Vintaging Model. For halons used in fire protection IRTA's estimates differed from those of a trade association.

III. STAFF COMMENTS

This project was subject to the 3 month work suspension in 2008 required by the Governor Schwarzenegger's Executive Order. Because of this suspension several activities in the original workplan had to be revised.

Some of the applications that were included in the original workplan were separately addressed by ARB in pursuing AB 32 Early Action Measures. A revised workplan adjusted for those changes in scope. The semiconductor sector was eliminated since the analyses in the original workplan were conducted during the process of developing the Semiconductor Perfluorocarbon Emissions Reduction Strategy regulation which was adopted in 2009. Similarly, the use of SF₆ in electric power transmission applications was also addressed during regulation development. The ARB Consumer Products staff indicated that any future ARB car tool programs would focus on GHG use in aerosol applications; this addressed the use of HFC propellants and HCFCs, HFCs, and HFEs used in aerosol cleaning applications.

The time originally budgeted for these applications was productively used by adding additional analyses and comparisons with other estimates of GHG stockpiles and uses from industry groups and the U.S. EPA Vintaging Model that were not in the original workplan.

A previous draft of the report was submitted and reviewed by several persons within ARB and IRTA's stakeholder contacts. Comments from those reviews were incorporated into this version.

IV. STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to the staff comments and any changes and additions specified by the Committee.

DISCUSSION OF FINAL DRAFT REPORT

ITEM NO: 7

DATE: October 28, 2011

CONTRACT NO.: 07-330

[Link to Report](#)

STAFF EVALUATION OF A FINAL DRAFT REPORT

TITLE: Lifecycle Analysis of High-Global Warming Potential Greenhouse Gas Destruction

CONTRACTOR: ICF International

PRINCIPAL INVESTIGATOR: Mark Wagner, Senior Vice President
ICF International
Pamela Mathis, Senior Manager
ICF International

BUDGET: \$297,766

CONTRACT TYPE: Standard Agreement

CONTRACT TERM: 36 months

For further information, please contact Pamela Gupta at (916) 327-0604.

I. SUMMARY

High global warming potential (GWP) greenhouse gases (GHGs) found in refrigerants, insulating foam, fire extinguishing agents, and stockpiled high-GWP solvents represent a significant source of potential GHG emissions. While a number of existing regulations already target the reduction of high-GWP gas “in-use” emissions, their recovery and reuse/destruction at product/equipment end-of-life (EOL) is a possible option to achieve further reductions. The objective of the research was to generate a lifecycle analysis (LCA) for the recovery and destruction options for high-GWP GHGs in order to develop and recommend the most cost-effective and practical approaches to reduce high-GWP GHG emissions from these sources. Six separate high-GWP emission sectors were investigated, with potential emission reductions and cost of those reductions developed for each sector. The sectors researched for recovery and destruction of high-GWP GHGs were: 1) residential refrigerator-freezers at time of disposal; 2) other stationary refrigeration and air-conditioning equipment at time of disposal (includes commercial refrigeration and air-conditioning, and residential air-conditioning); 3) non-refillable

refrigerant cylinders; 4) construction and demolition building insulating foam at time of disposal; 5) high-GWP fire extinguishing agents, and 6) high-GWP solvents. Emission reductions of up to 10.1 million metric tons CO₂ equivalent (MMTCO₂E) annually by 2020 could be achieved by increasing recovery of refrigerant from the sector of other stationary and air-conditioning equipment at time of disposal (sector includes all refrigerant-containing equipment except residential refrigerator-freezers), at a cost of \$2.36 - \$6.23/MTCO₂E reduction. Recovery and reclamation or destruction of high-GWP fire extinguishing agents results in 0.09 MMTCO₂E annual reductions by 2020, at a cost savings of \$2.01 to a cost of \$6.62/MTCO₂E. The remaining four sectors would result in net reductions of 0.3 MMTCO₂E annually by 2020, at higher reduction costs of \$77 - \$444/MTCO₂E reduction. Findings of the research will better inform ARB's greenhouse gas reduction strategy policies.

II. TECHNICAL SUMMARY

Objective

High-GWP GHGs found in refrigerants, insulating foam, fire extinguishing agents, and stockpiled high-GWP solvents represent a significant source of potential GHG emissions. A need exists for cost-effective strategies to mitigate the potential GHG emissions from these sources.

The objective of the research was to generate a lifecycle analysis (LCA) for the recovery and destruction options for high-GWP GHGs in order to develop and recommend the most cost-effective and practical approaches to emission reductions from this GHG sector.

The lifecycle study was able to make use of and leverage the results of three related high-GWP GHG inventory research contracts funded by ARB, without duplicating their efforts. The three related research projects are:

1. "Inventory of Direct and Indirect GHG Emissions from Stationary Air Conditioning and Refrigeration Sources, with Special Emphasis on Retail Food Refrigeration and Unitary Air Conditioning", Armines, Final Report March 2009; contract 06-325.

2. “Developing a California Inventory for Ozone Depleting Substances (ODS) and Hydrofluorocarbon (HFC) Foam Banks and Emissions from Foams”, Caleb Management Services, Final Report March 2011; Contract 07-312.
3. “Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers, and Ozone Depleting Substances”, Institute for Research and Technical Assistance (IRTA), Draft Final Report March 2011; Contract 07-313.

Researchers investigated the lifecycle cost-benefit of recovering and destroying high-GWP GHGs from the following sources:

- Residential refrigerator-freezer (appliance) insulating foam at time of disposal;
- Other stationary refrigeration and air-conditioning equipment at time of disposal or recycling (includes all high-GWP refrigerant-containing equipment except the residential refrigerator-freezers, which have their own category);
- Non-refillable refrigerant cylinders (spent, but with remaining refrigerant vapor known as the “heel”);
- Construction and demolition (C&D) building insulating foam at time of disposal;
- High-GWP fire extinguishing agents; and
- High-GWP solvents.

Background

The AB 32 Scoping Plan identified refrigerants, insulating foam, and fire extinguishing agents as potentially significant contributors of GHGs, and recommended recovery and destruction of the high-GWP compounds in climate change measures.

Refrigerants used in residential and commercial refrigeration and air-conditioning equipment have GWPs ranging from 1300 to 8100. Federal, state and local regulations (including ARB’s recently adopted Refrigerant Management Program) cover leak inspection and repair requirements and mandate refrigerant recovery at equipment EOL. However, the levels of compliance with such regulations are unknown and difficult to assess. None of the regulations specifically covered the cost-benefit of recovering

refrigerant from cylinders and equipment. However, due to numerous anecdotal reports that refrigerant was not always recovered from cylinders and equipment, a cost-benefit study was essential to determine the most cost-effective strategy to mitigate high-GWP GHG emissions from these sources.

Foams containing high-GWP greenhouse gases (GWPs ranging from 700 to 3800) are used as insulation for residential refrigerator-freezers and buildings. The greenhouse gases within the foam include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), and are used as foam expansion agents during foam production. Unlike refrigerant, no current regulations exist that require management of insulating foam GHGs.

High-GWP fire extinguishing agents include halons, which are ozone-depleting chemicals that have not been manufactured since the 1990s, but stockpiles of these high-value chemicals remain. Additionally, high-GWP HFC fire extinguishing agents are used (HFC-125, HFC-227ea, and HFC-236). High-GWP fire extinguishing agents have GWPs ranging from 1300 to 5400, and are not allowed to be vented unless used in an actual fire.

High-GWP solvents were added to the LCA as a result of findings from the previously mentioned IRTA high-GWP chemical inventory research report of 2011 (currently a draft final report). Although high-GWP solvents manufactured before 2003 have been replaced by low-GWP solvents, some stockpiles of older solvent remain, including CFC-113 (GWP of 5000), and HCFC-141b (GWP of 630). The older solvents have monetary value and are rarely disposed of illegally, but the solvents do evaporate during the normal course of use.

Project Summary

The research investigators interviewed industry experts and stakeholders to ascertain current business-as-usual (BAU), cost and benefit of various high-GWP GHG recovery and destruction scenarios.

For each identified emission source, the lifecycle analysis developed baseline BAU costs and emissions of current end-of-life disposal, recycling, or management practices of high-GWP GHGs. For each alternative scenario analyzed, the incremental cost

above BAU was calculated taking into account cost factors including infrastructure building and maintenance, labor, transportation, energy consumption, recycling or disposal, and capital costs. Emission benefits were developed by first calculating current emission baselines associated with high-GWP GHG management from recycling/recovery, energy use and transportation; and then comparing the same emission parameters to alternative management scenarios. Incremental emission benefits were calculated for GHG (in CO₂-equivalents), ozone-depleting substances (in ozone-depleting potential equivalents) and the criteria pollutants of NO_x, SO_x, PM₁₀, and PM_{2.5}.

Previous versions of the draft final report were submitted for comments and feedback to more than 70 stakeholders in industry, environmental organizations, and federal and state government agencies. Fifteen separate stakeholders submitted a total of 177 comments. Comments and feedback were incorporated into the report, which refined the inputs and assumptions used in cost analysis, greatly improving the overall approach and strengthening the findings.

The main findings of the research to determine lifecycle cost-benefit of recovering and destroying high-GWP GHGs from the following sources are summarized below:

1. Residential refrigerator-freezer (appliance) insulating foam: Annual emission reductions of 0.26 MMTCO₂E can be achieved through appliance insulating foam recovery and destruction programs, at an average cost of \$77/MTCO₂E reduction. The added recycling cost is approximately \$17 to \$43 per appliance, depending upon whether appliances are recycled at existing appliance recycling facilities, or if additional new recycling facilities must be built.
2. Other stationary refrigeration and air-conditioning equipment: Recovery of refrigerant from stationary refrigeration/AC equipment at EOL is required by federal law, but actual compliance is difficult to assess and enforce. If additional measures are considered to bolster recovery requirements such that a 90 percent compliance level is achieved, significant GHG emissions can be avoided. By achieving a 90 percent recovery rate in lieu of only 10 percent, annual emission reductions of

up to 10.1 MMTCO₂E can be achieved by 2020, at a cost of \$2.36 to \$6.23/MTCO₂E reduction.

3. Non-refillable refrigerant cylinders: Current ARB refrigerant management program regulations require the evacuation of any remaining refrigerant (the “heel”) in any spent, non-refillable refrigerant cylinder. If these regulations are successful, emissions from spent cylinders are expected to be negligible, and no additional cylinder reduction programs are necessary. The LCA research began prior to the adoption of the ARB cylinder requirements, and therefore, a cost-benefit analysis was conducted for the hypothetical scenario where non-refillable cylinders are banned and only refillable cylinders used. Minor annual emission reductions of 0.02 MMTCO₂E could be achieved at a relatively high cost of \$254-\$444/MTCO₂E reduction.
4. C&D building insulating foam: GHG emissions from waste building foams were estimated to be 4.4 MMTCO₂E annually in 2010, increasing to 6.3 MMTCO₂E by 2020. However, recovering the insulating foam from building C&D waste is extremely labor intensive, resulting in a GHG reduction cost of \$300/MTCO₂E reduction, believed to be too cost-prohibitive to be feasible. However, one specific type of insulation, steel-faced foam insulating panels (representing less than 10 percent of waste building foam), was identified as a material that already undergoes recycling for the metal content. Foam recovery and destruction from the steel-faced panels could be added to the recycling process, resulting in GHG emission reductions of 0.01 MMTCO₂E annually by 2020 (increasing to about 0.03 MMTCO₂E by 2040), at a reduction cost of \$102/MTCO₂E.
5. Fire extinguishing agents: Current GHG banks (total stored amount) from this sector are 0.16 MMTCO₂E, expected to decrease to 0.09 MMTCO₂E by 2020. Annual emissions are negligible, as these extinguishing agents have significant value and are not intentionally vented or disposed of. Recovering and reclaiming the extinguishing agents results in a net benefit [value] of \$2.01/MTCO₂E. If the extinguishing agent is recovered and then destroyed, the cost effectiveness is \$3.56 - \$6.62/MTCO₂E reduction.

6. High-GWP solvents: Lower-GWP solvent alternatives have largely replaced ozone-depleting CFC and HCFC solvents with high GWPs. Current GHG emissions from high-GWP solvents are relatively insignificant at 0.028 MMTCO₂E annually, and are expected to decrease 50 percent by 2020, to 0.014 MMTCO₂E. The cost effectiveness to recover and destroy stockpiled solvents is \$3.75/MTCO₂E reduction, which is generally considered very cost-effective.

III. STAFF COMMENTS

This study was the first to investigate potential costs and benefits in California of recovering and destroying high-GWP GHGs from the six high-GWP sectors analyzed. The research has improved and expanded our understanding of the full lifecycle cost and benefit of reducing GHGs from refrigerants, foam expansion agents, and solvents. The results and conclusions will be used by ARB to better inform development of climate change measure policy regarding reduction of high-GWP GHGs.

IV. STAFF RECOMMENDATIONS

Staff recommends that the Research Screening Committee approve this draft final report, subject to inclusion of appropriate revisions in response to the staff comments and any changes and additions specified by the Committee.

DISCUSSION OF NEW RESEARCH PROJECT

ITEM NO: 1

DATE: October 28, 2011

CONTRACT NO.: 08-323

STAFF EVALUATION OF A REQUEST FOR A CONTRACT AUGMENTATION

TITLE: Black Carbon and the Regional Climate of California

CONTRACTOR: University of California, San Diego

PRINCIPAL INVESTIGATOR: V. Ramanathan, Ph.D.

ORIGINAL BUDGET: \$796,403

CONTRACT AUGMENTATION: \$24,080

CONTRACT TYPE: Interagency Agreement

CONTRACT TERM: 42 months

For further information, please contact Dr. Dongmin Luo at (916) 324-8496.

I. SUMMARY

Black carbon (BC) is a major component of aerosol particles that is generally emitted by combustion sources such as automobile exhaust and biomass burning. BC is the main light-absorbing component of atmospheric aerosols and has been tied to regional climate change by its contribution to global warming and the suppression of precipitation. Unlike other greenhouse gases (GHG), BC has a short atmospheric lifetime resulting in a strong correlation to regional emission sources. Hence, the mitigation of BC warming effects by emission controls can be a viable policy. The objective of original research proposal, which was approved by the RSC on January 23, 2009, is to assess the impact of BC on California's climate by developing a balanced approach between observations, data analyses, and modeling studies. The first set of results from the existing ARB funded study have led to a major finding by showing that the particulate matter control policies as implemented by California have resulted in a reduction of atmospheric BC by 50 percent. In this supplemental study, the investigators propose to analyze surface solar radiation flux measurement data to explore the link between policies on diesel emissions and climate mitigation. This

request for supplementary funds (\$24,080), if approved, can provide additional unique data set for understanding the BC radiative forcing from an observational perspective and thus provide a first of its kind data set to validate model predictions of BC radiative forcing and provide direct observational data for BC mitigation actions. Hence, the investigation is expected to enhance informed policy-making on mitigating BC emissions.

II. TECHNICAL SUMMARY

Objective

The objective of this proposed study is to analyze surface solar radiation flux measurement data to explore the link between policies on diesel emissions and climate mitigation. The project has the potential to verify with observational evidence the total radiation benefit of combined BC and sulfur controls (which is thought to have a counteracting impact to BC) for the first time.

Background

Atmospheric aerosols play an important role in the global climate system through modifications of the global radiation budget: directly by scattering and absorption of radiation; and indirectly by the modification of cloud properties. Recently, the issue of BC has moved to the science and policy mainstream given the global focus on climate change. According to a recent assessment, BC is the second largest contributor to global warming with an estimated radiative forcing of 0.9 W/m^2 , next to 1.6 W/m^2 for carbon dioxide.

BC aerosols in clouds can enhance the absorption of solar radiation, increase cloud evaporation, and decrease cloud lifetime by heating the atmosphere. Deposition of BC on snow and ice may reduce the reflectivity of the surface, leading to faster and earlier melting of glaciers, sea ice, and mountain snow packs. Lastly, when BC is internally mixed with sulfate, nitrate, or organic carbon, the absorption efficiency significantly increases. California's regional climate may be especially sensitive to these radiative effects of BC; a recent California specific study shows that the darkening of snow and ice by BC deposition is a major factor for the rapid disappearance of our snow packs. The early melting of the snow packs in the Sierras is one of the contributing factors to the severe water problems in California. The potential impact of aerosols including BC

on precipitation and freshwater availability has recently received increasing attention given California's push for economy-wide GHG reductions. Another recent study has tied an observed increase in frequency and duration of wildfires in the western United States to warmer temperatures, earlier snowmelt, and drier summers. Furthermore, in a potentially unfortunate feedback loop, increases in wildfires further amplify the concentration of light-absorbing carbon particles and subsequent climate impacts on California. Policymakers and air quality regulators are seeking better understanding of the magnitude and importance of the BC radiative impacts and the subsequent climate response in order to better assess the role of BC in the GHG emission control programs.

Proposal Summary

The University of California, San Diego (UCSD) research project aims to determine the impact of BC on California's climate by developing a balanced approach between observations, data analyses, and modeling studies. The three tasks in the original research proposal fall under two broad categories: observational estimates and regional modeling studies with data assimilation.

- Task 1: Spatial and temporal patterns in BC concentrations using ARB Coefficient of Haze (COH) data
- Task 2: Multi-platform data analysis for BC and other aerosol properties
- Task 3: Assessment of climate impacts due to BC based on derived radiative forcing

Task 1 included one year operation of the refurbished COH monitors side-by-side with aethalometers in San Jose and Vallejo. All available COH data from 1963 to 2003 for California have been compiled, and monitoring sites have been grouped by air basin. Historical trends in COH-inferred BC concentrations have been processed for each air basin. Annual averages, seasonal trends by decade, and weekly cycles by decade have all been plotted for each air basin.

Task 2 included comprehensive compilation and data assimilation for BC from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, aerosol single scattering albedo (SSA) from the AERONET network, Aerosol Optical Depth (AOD) from MODIS and MISR satellites, BC deposit measurements in snow,

Aerosol-Time-Of-Flight Mass Spectrometer (ATOFMS) data sets for evaluating mixing states, and unmanned aerial vehicles (UAV) measurements for determining vertical profiles in the time period from 2001 to 2007. AERONET is a global aerosol-monitoring network of ground based sun photometer measurements.

Task 3 involved utilizing the gridded data sets from Task 2 in conjunction with climate models to evaluate the short- and long-term contribution of BC to radiative forcing and its impact on California's climate.

The first set of results from existing ARB funded study have led to a major finding by showing that BC over California's IMPROVE sites have decreased by as much as 50 percent. This implies that the PM control policies as implemented by California have resulted in a reduction of atmospheric BC by 50 percent. Application of the column-integrated model indicates a resultant solar brightening of 5.6 W/m^2 at the surface due to the reduction in absorbing aerosols. Such a large change in BC radiative forcing should be detectable with surface radiation data.

The California Irrigation Management Information System (CIMIS) manages an integrated network of over 120 automated weather stations in the State of California dating back to 1982. The CIMIS network provides hourly measurements of the surface solar flux at stations distributed throughout California. In order to better constrain these results and obtain observation based confirmation, the investigators are requesting supplementary funds to conduct analyses of this data set for trends in solar radiation at the surface.

The investigators will use the CIMIS dataset in conjunction with AERONET measurements to determine long-term trends in surface brightening or dimming. They will adopt a two-pronged approach to separate trends in clear-sky solar flux from the cloudy-sky solar flux. This is because accurate measurements of the solar flux reaching the surface in cloud-free conditions are required for comparison with the modeled aerosol radiative impact of the 50 percent reduction in BC over California. The COH data provide a direct measurement of the visibility conditions constrained by carbonaceous aerosols. The investigators will also compare 20-year trends in COH and solar flux in each of the California basins to provide a direct link between the expected

surface brightening, observed solar flux, and reduction in BC emissions in California. Inclusion of this solar flux data has the potential to greatly enhance the conclusions and results of the original research project by:

1. Providing an observational tool for constraining predictions of radiative forcing and surface brightening;
2. Providing a metric for determining the relative significance and magnitudes of the direct, indirect, and semi-direct effects of BC.

III. STAFF COMMENTS

An early version of the proposal was reviewed by staff from ARB's Planning & Technical Support and Research Divisions. The current version has incorporated staff comments fully. Dr. Ramanathan is the principal investigator coordinating and synthesizing the effort of other task leaders. He has led several major projects such as the Indian Ocean Experiment and the Earth Radiation Budget Experiment, and is known for his contributions to the area of atmospheric aerosol research. The USCD proposal has also assembled a large number of experts with wealth of knowledge in performing tasks identified in this study.

Although there have been repeated suggestions that reduction of BC could be a viable part of decreasing global warming, it has not yet been considered when choosing actions to reduce climatic impact. The BC warming effect offers an opportunity to mitigate the projected warming trends in the short term as suggested by recent studies. In particular, BC reduction may provide a possible mechanism for buying time to develop and implement effective steps for reducing GHG emissions. There is a pressing need for resolving uncertainty in quantifying the climatic effects of BC and informing policymakers and air quality regulators of the magnitude and importance of the BC radiative impacts, and the subsequent climate response. The result of this study has immediate value for understanding the pathways by which BC could be of importance in California's climate change, and will enhance ARB's policy-making on the regulation of BC emissions.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve the contract augmentation for a total amount not to exceed \$24,080, subject to any changes and additions specified by the Committee.